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# Development of a New Methodology for Modeling the PV Generator Behavior in the Presence of Open-Circuit and Short-Circuit Faults

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**Abstract**— In this paper, we proposed a new methodology for the faults photovoltaic generator modeling, especially when it subjected to the open-circuit and short-circuit faults at its components: cells, bypass diodes and blocking diodes. The highlight of the proposed algorithm focused on the mathematical modeling that based on known electrical laws, of the IV characteristic of the faulty PV generator.

This model is able to develop a rich data-base, containing six electrical faults types, which can uses in the diagnosis area of the photovoltaic generators.

**Index Terms** — PV Generator; I-V characteristic; Modeling; Simulation; Short-Circuit and Open-Circuit Faults.

## NOMENCLATURE

$I_{SRC}$	= String Reversed Current.
$I_{SSC}$	= String Supplied Current.
$I_{Cell}$	= Cell Current.
$V_{Cell}$	= Cell Voltage.
$I_{Cell\_Short\_Circuit}$	= Cell Short Circuit Current.
$V_{Cell\_Open\_Circuit}$	= Cell Open Circuit Voltage.
$nc$	= Cells Number.
$I_{Group}$	= Group Current.
$V_{Group}$	= Group Voltage.
$I_{Bypass\_Diode}$	= Bypass Diode Current.
$ng$	= Groups Number.
$I_{Module}$	= Module Current.
$V_{Module}$	= Module Voltage.
$nm$	= Modules Number.
$I_{String}$	= String Current.
$V_{String}$	= String Voltage.
$ns$	= Strings Number.
$I_{PV}$	= Generator Current.
$V_{PV}$	= Generator Voltage.
$PHI$	= Photo-Current.
$I_0$	= Reverse Saturation Current.
$DTV$	= Diode Thermal Voltage.
$a$	= Diode Ideality Factor.
$R_s$	= Cell Series Resistance.
$R_{SH}$	= Cell Shunt Resistance.
$V/I$	= Voltage / Current.
$V_{imposed}$	= Voltage Imposed.

## I. INTRODUCTION

Photovoltaic solar energy is the energy recovered from the conversion of the light energy (solar) to the electrical

energy, by a photovoltaic generator system. It composes of photovoltaic cells series, when they subject to the light produce a direct-current and a voltage typically between 0.5 to 0.6 volts for each one. These cells are placed in series for objective to increasing the generator voltage, and in parallel to increasing the generator current. And for the utilization of this energy, it is necessary to use converters to transform the direct-current to the alternating-current [1-2].

A photovoltaic generator subjects during its functioning to the various defects, which they decrease its productivity, and also increase its operation and maintenance costs [3-4]. These factors and by the diversity of the defects types push the researchers to develop the modeling algorithms of the faulty photovoltaic generators, which given its operation knowledge [5-6]. These algorithms facilitate the faults prediction and detection of the generator, for making the prognosis, the diagnosis, the maintenance of its faulty components, and finally to ensuring its healthy functioning [10-12].

In this context, the paper objective is the development of the faults modeling algorithm of the photovoltaic generator. So, the paper contributions are twofold: 1) the growth of a new mathematical model of the PV generator operation, when it subjected to the open-circuit and short-circuit faults at its basic components as its cells, its bypass and blocking diodes. 2) This new model is presented as a hierarchy, from the smaller member which is the PV cell to the largest unit which is the generator, passed by intermediate entities: group of cells, module and PV string.

## II. MODELING THE PHOTOVOLTAIC GENERATOR IN MALFUNCTIONING

Among the most dangerous and known defects in the diagnosis area of a PV generator is the *open-circuit* fault. It's usually appears in the presence of cracks at generator components as the cells, due to a burning and a ranking, or at the wiring due to friction with its environment. The appearance of this fault type leads to permanent replacement of the faulty components, because it becomes unusable.

Also, among the major faults known in the PV generator diagnosis area, an electrical fault very dangerous, its appearance concludes the decrease in the

PV generator voltage, and also an increase in its temperature, this defect called a *short-circuit*. It appears in accidental contact between two conductors of different polarity, it produces a current higher than the normal.

The causes of this fault are multiple, because they are dependent on the actuators, either within the system itself such as the surge maneuver, semiconductor breakdown, insulation degraded by wear or corrosive products, either within the climate such as lightning, flood, fire, vibration, heat, humidity, or property of the system outside such as wiring errors, the presence of a bolt, screw, other

conductive objects.

This defect cannot degrade the productivity, stopped production electric and decrease the beginning of the system only, but it can also degrade the equipment and its circuits, and in some cases creates a hazard to the environment persons by electrocution, fire and burns, due to their death or blindness in humans. The influence modeling of the open-circuit and short-circuit faults on the PV generator hierarchy presents in Figure1 consists of three main parts:

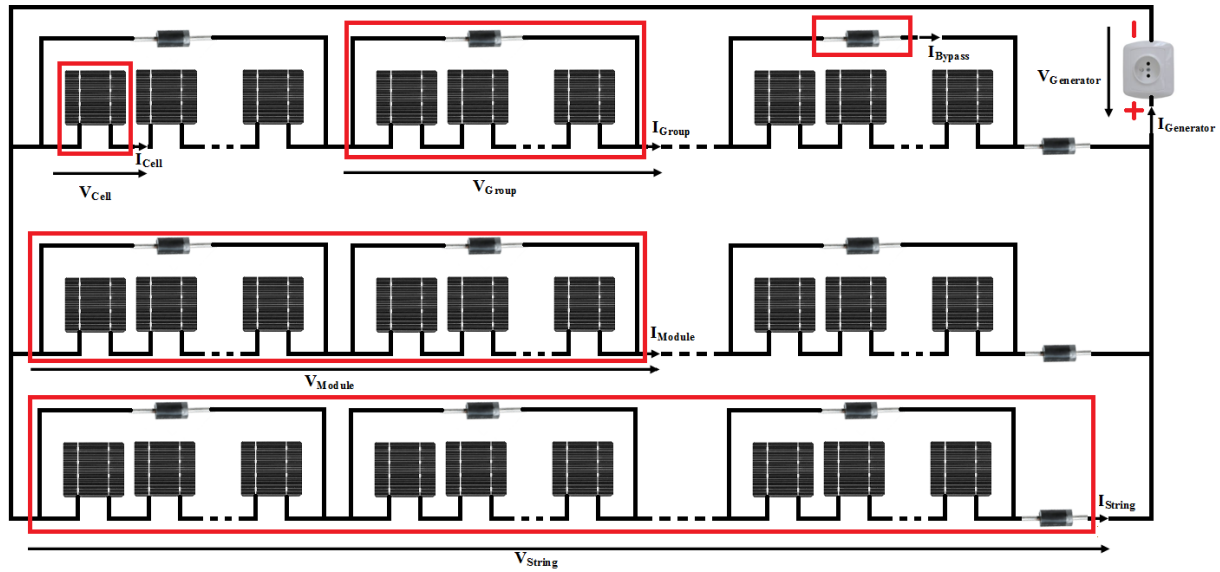


Figure1. PV generator description

#### A. Influence Modeling of the Short-Circuit and Open-Circuit Blocking Diodes on the PV Generator Hierarchy

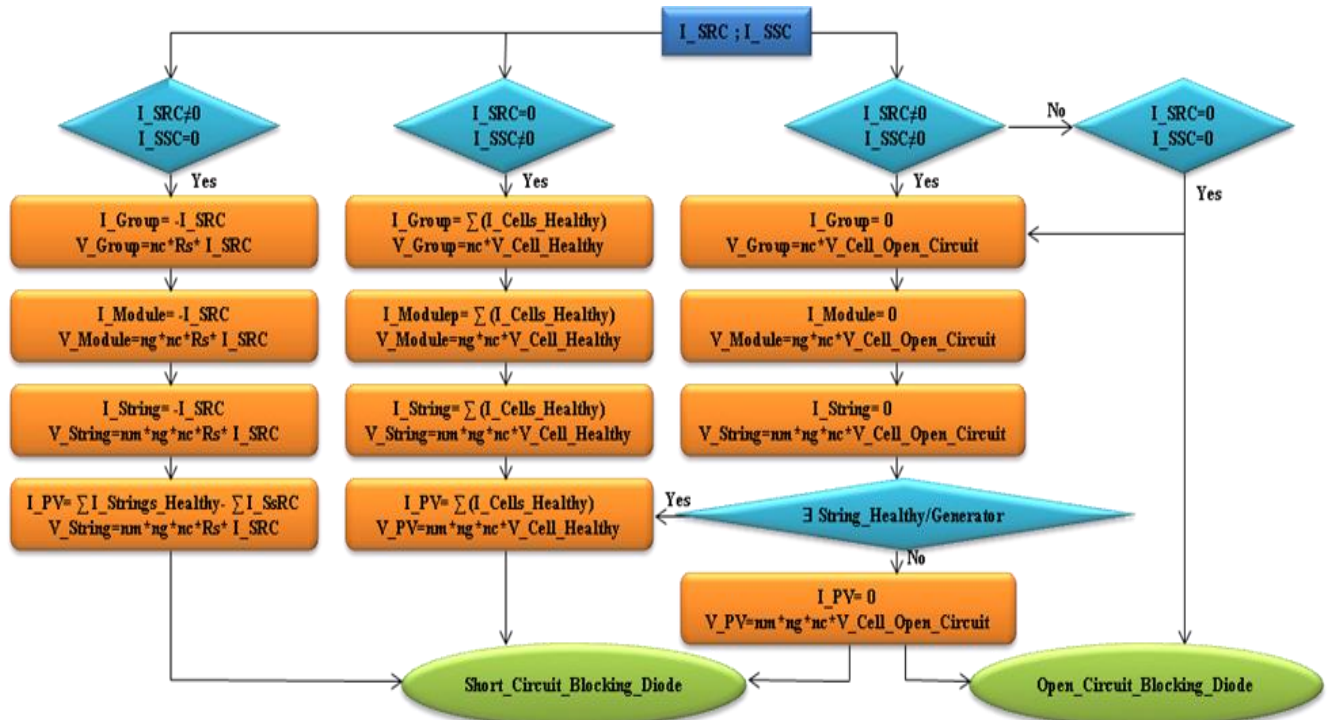


Figure2. Flowchart for Influence Modeling of the Short-Circuit and Open-Circuit Blocking Diodes on the PV Generator Hierarchy

### B. Influence Modeling of the Short-Circuit and Open-Circuit Cells on the PV Generator Hierarchy

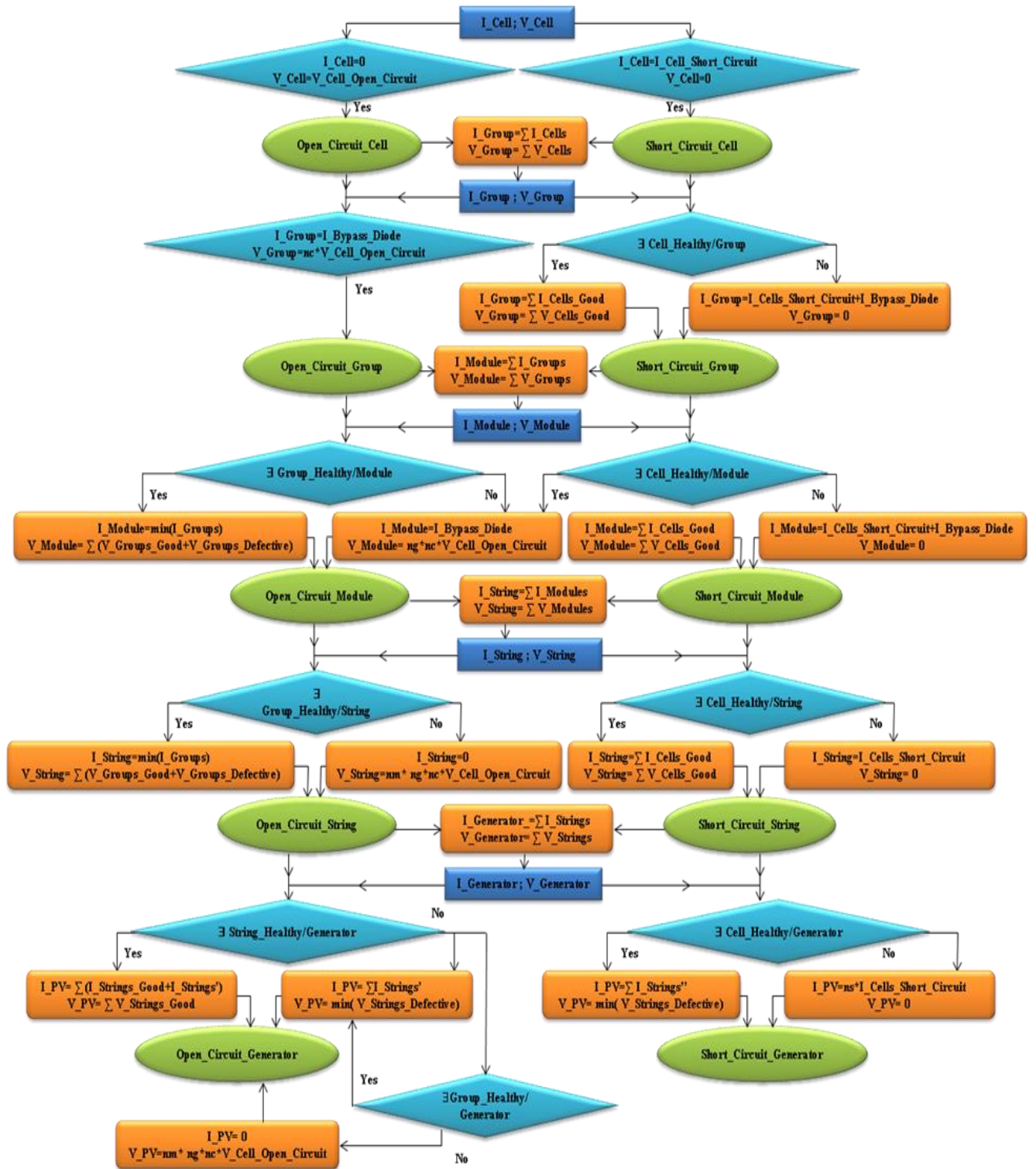


Figure3. Flowchart for Influence Modeling of the Short-Circuit and Open-Circuit Cells on the PV Generator Hierarchy

With:

String' = Defective Strings Number, where each one contains at least one good group.  
 String'' = Defective Strings Number, where each one contains at least one good cell.



### C. Influence Modeling of the Short-Circuit and Open-Circuit Bypass Diodes on the PV Generator Hierarchy

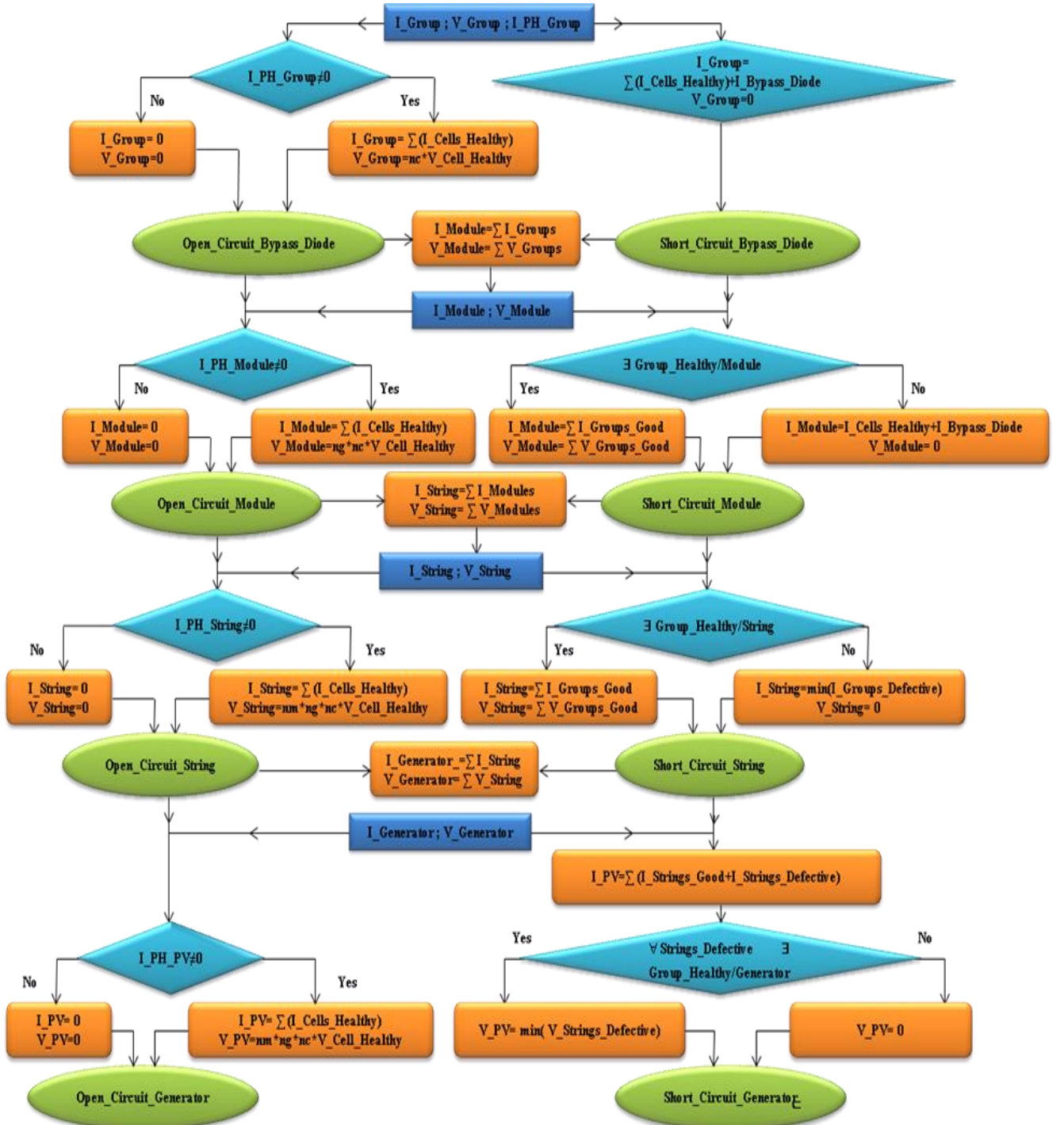


Figure4. Flowchart for Influence Modeling of the Short-Circuit and Open-Circuit Bypass Diodes on the PV Generator hierarchy

### III. MODELS SIMULATION AND RESULTS INTERPRETATION

In this work, we use for the mathematical modeling of the generator in its good and faulty behavior the model *one diode* of the photovoltaic cell as presents in Figure5. We have chosen this model, because it's the most model used in the scientific research work or by manufacturers, thanks to the availability of the technical characteristics of the photovoltaic cell in the data-sheets.

This model consists of a current source, a diode, a shunt resistance  $R_{sh}$  represents the energy loss in the region of the PN junction of the cell, and a series resistance  $R_s$  that is the resistance of the semiconductor and electrodes of the cell. Mathematical modeling of the voltage and the current supplied by the generator in its normal operation are:

$$\begin{cases} V_{PV_{np}} = nm \times ng \times nc \times V_{Cell\_imposed} \\ I_{PV_{np}} = ns \times \left( \phi - I_0 \times \left( e^{\frac{V_{Cell} + I_{Cell} \times R_S}{a \times DTV}} - 1 \right) - \frac{V_{Cell} + I_{Cell} \times R_S}{R_{SH}} \right) \end{cases} \quad (1)$$

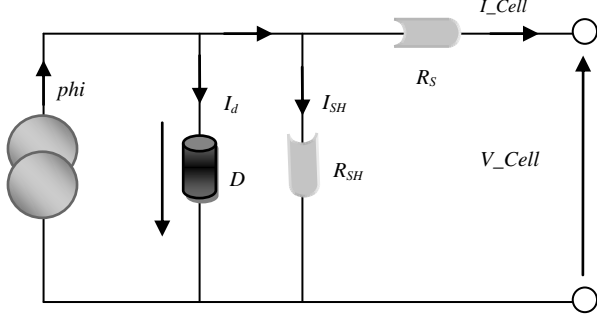


Figure5. One diode model of the photovoltaic cell

The results simulations of the PV generator model are shown in the following Figures 6 to 7.

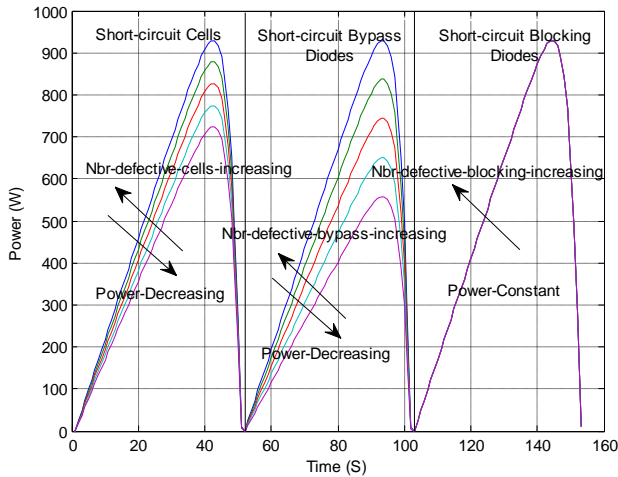


Figure6. The influence of the short-circuit fault on the PV generator functioning

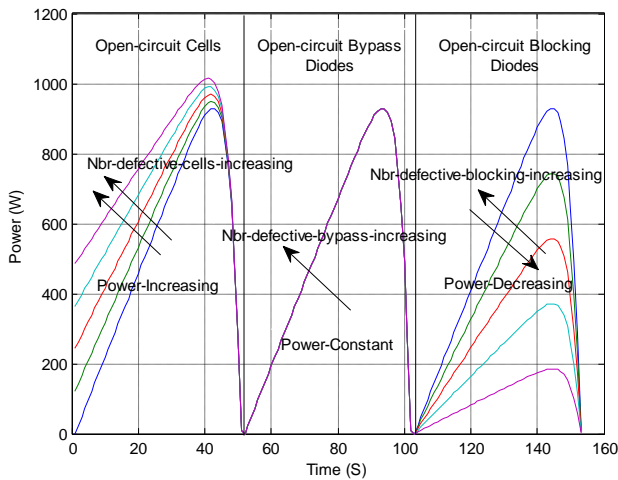


Figure7. The influence of the open-circuit fault on the PV generator functioning

From the results, we found that:

✓ The influence of the short-circuit cells fault on the generator productivity is less than the short-circuit bypass diode fault influence. Because, the first fault type affects the defective cell power only, but the second fault type affects all the cells group power.

✓ The short-circuit blocking diode fault has no influence on the generator operation, while its strings provided the same voltage value. Else this faulty type affects the generator power. Because, if there is at least one of its faulty strings with a minimum voltage, so this latter becomes in a receiver mode if its cells current is null, else this faulty string becomes in the open-circuit mode.

✓ The open-circuit cell and connections between cells open-circuit faults influence - which have the same impact- on the generator productivity are less than the open-circuit blocking diode and connections between groups open-circuit - which have the same impact- faults influence. Because, the first faults types affect the defective cell power, but the second faults types affect the string power.

✓ The open-circuit fault at the bypass diode has no influence on the generator productivity, while its cells group is in the normal operation. Else this faulty type can affects the string power.

#### IV. CONCLUSION

This paper proposed a new methodology for the mathematical modeling of the PV generator operation, which subjected to the open-circuit and short-circuit faults.

This new methodology based on three algorithms, each one presents the influence modeling of the two defects: open-circuit and short-circuit at the same type of the generator components: either the PV cells, or the bypass diodes, or also the blocking diodes.

The future work of these algorithms is to make the hybridization between 1) the existence of two faulty components: of the same types, but of different defects. 2) Or the existence of two faulty components: of different types, but of the same defects, as prospects.

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